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PLASMA PHYSICS RESEARCH INSTITUTE
LAWRENCE LIVERMORE NATIONAL LABORATORY
UNIVERSITY OF CALIFORNIA, DAVIS

ANNUAL REPORT
FOR
FISCAL YEAR 1989

Acting Director: John Killeen
Acting Director: R. Paul Drake

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I. Introduction

The Plasma Physics Research Institute (PPRI) was established in 1987 as a joint UC-LLNL organization. Its purpose is to strengthen basic and applied research in plasma science throughout the University. The PPRI makes the facilities and expertise of LLNL more available to campus scholars in fields of interest to the Institute. Research on fundamental issues in plasma physics is its primary focus. At present, the PPRI receives support from the UC Institutes Program of LLNL, from the Department of Applied Science at UC Davis, and from other LLNL programs.

In FY89, the program of the PPRI expanded to contain the following elements:

- The Davis Diverted Tokamak
- A joint LLNL-UC Berkeley particle-simulation of fusion plasmas project
- A joint LLNL-UC Berkeley theoretical and computational astrophysics project
- A joint LLNL-UC San Diego theoretical study of plasma turbulence
- A joint LLNL-UC Los Angeles numerical simulation of ionospheric plasma modification supporting experiments at HIPAS Observatory in Alaska
- A joint LLNL-UC Los Angeles experiment at Aerocibo and supporting numerical simulation of ionospheric density modification
- A joint LLNL-UC Davis experiment at the LLNL JANUS laser facility to study ion acoustic decay instability
- Summer visitor program: W. Lawson (New York University), N. Otani (Cornell), S. Jardin (Princeton), G. Rowlands (Warwick, UK), and K. Nishihara (Osaka, Japan)

During this year the PPRI hired post-doctoral fellows in support of two of these research projects. Dr. James H. Rogers works with the Davis Diverted Tokamak and Dr. James A. Crotinger works on the collaboration with UC San Diego to explore plasma turbulence.

Accompanying the expansion of its research programs, the PPRI became more permanent as an institution. A search committee composed of Laboratory and campus physicists and chaired by Bruce Cohen conducted a national search and interviewed candidates for a first permanent director of the PPRI, which lead to the designation of Paul Drake to succeed John Killeen as Acting Director of the PPRI in September 1989. The confirmation of Paul Drake's appointment as Director awaits review by the UC Davis Academic Senate. Meanwhile, the confirmation of the PPRI as an Organized Research Unit of the University has been recommended by President Gardner's office to the state-wide Academic Senate. In addition, the PPRI convened a committee of distinguished plasma physicists from throughout the UC system in April to review and rank collaborative research proposals for FY90 which were solicited by a formal call for proposals during the winter of 1989.

In FY89, the PPRI received $262,000 in funds from the UC Institutes Program of LLNL.

II. Plasma Physics Research Institute 1989 Summer Visitor Program

There were four plasma physicists visiting Lawrence Livermore National Laboratory and the Department of Applied Science, UC Davis (Livermore campus) under the auspices of the Plasma Physics Research Institute. These physicists and their research activities are described briefly in the following.

Dr. Niels Otani is an Assistant Professor at Cornell University who visited from July 23 to August 19. He is developing a one-dimensional particle simulation code to study the interaction between double layers and kinetic Alfvén waves, which is of interest in space plasma physics and solar plasma physics. He interacted with physicists at IGPP, as well as Bruce Langdon and Dennis Hewett in X Division; Bruce Cohen, Jack Byers, and Yoshi Matsuda in M Division, and Jacques Denavit in A Division.

Dr. Steve Jardin is a Senior Research Physicist at the Princeton Plasma Physics Laboratory, Princeton University. His visit extended from August 1 to August 31. His research specialty is the realistic simulation of magnetohydrodynamic equilibrium stability, transport, and resistive effects in tokamaks. He has been collaborating for the last two years with M Division theorist Tom Kaiser who is using Steve's code TSC to model the evolution of equilibria in ITER plasmas and to evaluate certain MHD instabilities relevant to these configurations. He worked with T. Kaiser and D. Pearlstein to add a capability to the tokamak simulation code to allow the TSC shape-control feedback system to make use of control matrices generated by the LLNL equilibrium code TEQ. They also extended the ITER current-rise studies done by T. Kaiser to include PEST MHD stability analysis of the evolving equilibrium, and began a project to improve the current-drive physics package in TSC.

Professor George Rowlands is from the University of Warwick, United Kingdom. George is a theoretical plasma physicist who has had a long association with the magnetic fusion research program in the UK and the US, and visited M Division for a year on sabbatical leave some years ago. He worked with M Division and the Center of Compressible Turbulence theorists on the theory of coherent structures in plasma turbulence with an eye on the applications to anomalous transport in tokamaks. He visited from August 1 to September 15.

Dr. K. Nishihara is a plasma theorist from Osaka University. He visited from August 17 to November 10. His research expertise is in computational plasma physics and inertial confinement fusion. He has worked on implicit particle-in-cell methods. He collaborated with D. Hewett in X Division.

III. Summary Reports of Research Collaborations

THE DAVIS DIVERTED TOKAMAK

Principal Investigator: *D. L. Hwang*
University of California, Davis
Co-Investigators: *J. H. Rogers, J. C. Thomas, G. Dimonte, B. I. Cohen, D. E. Shumaker, K. Baker*
Lawrence Livermore National Laboratory
R. Evans, and T. Hillyer
University of California, Davis

Abstract

The Institute continued to support research on the Davis Diverted Tokamak, so named because it employs a magnetic divertor to control plasma impurities and stabilize the edge plasma. The facility has successfully demonstrated the beat-wave coupling of two X-band radar microwave sources to resonantly excite plasma oscillations in the torus for the purpose of driving a current. This research effort has received external funding from the Division of Applied Plasma Physics at the Department of Energy.

Summary Report

In FY89 the Davis Diverted Tokamak (DDT) construction was completed and initial experiments investigating beat wave current drive were performed. A three year contract was awarded in July from DOE to fund the beat wave experiment. These experiments were performed in low magnetic fields (25-50 Gauss), and with low plasma densities $(<10^{11}\mathrm{cm}^{-3})$. Full power ohmically heated discharges are expected to be performed early in FY90. Diagnostics which have been installed and tested in FY89 include a microwave interferometer (94 GHz), Langmuir probes, RF antenna, and a Rogowski coil.

The DDT is designed to be a general purpose tokamak which can investigate basic plasma physics issues important to large tokamaks. The experiments performed on the DDT are primarily dissertation projects performed by students of UC Davis, Department of Applied Science (DAS). During the summer, two new students started working on the DDT (bringing the total to three) and a post-doctorate was hired. Future experimental topics planned for these students include compact toroid injection into a tokamak, magnetic diverter physics, and lower hybrid current drive to stabilize the plasma. A 800 MHz, 50 kW klystron system has been acquired from the Princeton Plasma Physics Laboratory to be used for the lower hybrid experiment. Compact toroid generation is being actively researched by the RACE program at LLNL. The technology advancements and knowledge base of this group will be of benefit to the compact toroid experiment.

The first experiment being performed on the DDT is investigating beat wave current drive in a tokamak. In this experiment, two counter propagating microwave beams resonantly drive a plasma wave at the beat frequency. The wavelength of the plasma wave is determined by the microwave driver wavelengths ($\vec{k}_e = \vec{k}_1 + \vec{k}_2$) and the phase velocity of the plasma wave is much larger than the thermal electron velocity. Theory suggests[1] that the energy in the plasma wave will couple to the electron distribution via Landau damping or electron trapping, creating a suprathermal electron tail in the direction of $\vec{k}_e$. Unlike many other current drive techniques, propagation of the driver beams to the resonant region is not a problem, since ω_1, $\omega_2 > \omega_{pe}$, ω_{ce}. The results of this experiment should be of interest to the MTX program.[1]

In FY90, the DDT will begin operation as a tokamak with ohmic heating and magnetic diverters. The operating regime of density, temperature and confinement time will be measured. The first publications for the beat wave experiment will be submitted, and new proposals for additional funding to outside agencies will be generated in FY90.

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[1] B. I. Cohen, *et. al. Nuclear Fusion* **28**, 1519 (1988).

PARTICLE SIMULATION OF TRANSPORT IN FUSION DEVICES

Principal Investigators: *C. K. Birdsall and E. C. Morse*
Co-Investigators: *R. J. Procassini*
(Electronics Research Laboratory, University of California at Berkeley)
B. I. Cohen
(Magnetic Fusion Energy Division, Lawrence Livermore National Laboratory)
October 17, 1989

Abstract

This collaboration is focused on the application of the one-dimensional, relativistic, implicit electrostatic particle code TESS to the simulation of edge plasmas in magnetic confinement devices. Simulations of tokamak divertors were undertaken. The code was also successfully compared against a Fokker-Planck code to assess its accuracy and efficiency in simulating collisional phenomena self-consistently. An important extension was introduced in TESS with the invention of an alternate method to determine the collector-sheath potential drop semi-analytically without requiring the code to resolve the Debye sheath.

Summary Report

Our research in the area of transport processes in fusion devices has recently been centered on the development of particle simulation models of transport in the scrape-off layer (SOL) of a diverted tokamak. As part of this research, we have been involved in the development of a suitable boundary condition for the plasma current at a floating plate that allows use of long time- and space-scale implicit simulation techniques. We have also been involved in a comparison of results from our particle-in-cell (PIC) code and a bounce-averaged Fokker-Planck (FP) code for the study of particle confinement in an auxiliary heated mirror plasma. The graduate student at UC Berkeley involved in this research will receive his Ph.D. for this work this year.

Diverter/Scrape-Off Layer Transport Studies

Low-Recycling Divertor Systems

The effect of Coulomb collisionality on the transport of particles and energy to a low-recycling divertor plate through the SOL in a tokamak has been studied using the fully-kinetic, self-consistent PIC model. The two species (electron and ion) PIC code features a Monte Carlo binary-particle collision model which conserves the momentum and kinetic energy of the interacting particles. The full-range of Coulomb collisional processes (e-e, e-i and i-i) are included. The dependence of the presheath and collector sheath potential drops, plasma temperature, flow velocity and parallel heat flux on the collisionality was determined. The "collisional" presheath drop, electron temperature at the plate, and collector sheath drop were found to increase with collisionality (see Figure 1). The electron temperature at the plate is much smaller than the source temperature, due to the loss of electrons over the collector sheath potential barrier. The electron heat flux, which is the main channel for energy transport along the field lines in the SOL, is reduced relative to the "free-streaming" heat flux $q_{fs} \int n_e v_{te} kT_e$, finite (non-zero) values of the mean-free path $l \int v_{te}/v_{coll}$.

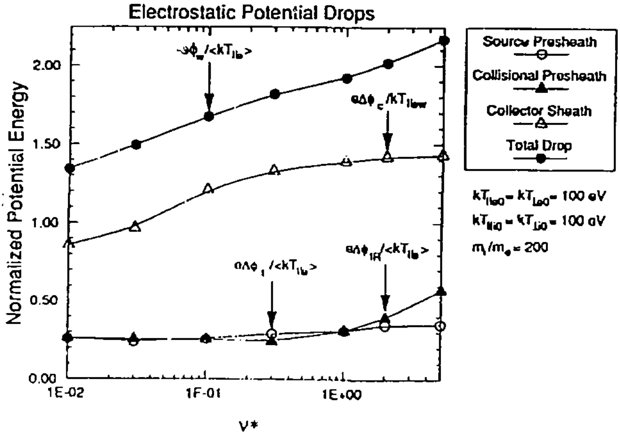

Figure 1: Variation of the source sheath ($\Delta\phi_1$), collisional presheath ($\Delta\phi_{IR}$), collector sheath ($\Delta\phi_c$), and total potential (ϕ_w), drops a function of collisionality ($\nu^* \equiv (\nu^{c/c}_{coll}/\nu^{c}_{bounce})$ in a low -recycling divertor scrape-off layer.

High-Recycling Diverter Systems

The effect of neutral/charged particle interactions on the transport of particles and energy to a high-recycling divertor plate through the SOL in a tokamak is under investigation using our fully-kinetic, self-consistent PIC model. In addition to a Monte Carlo binary-particle Coulomb-collision model, the basic electrostatic particle code also simulates the charge-exchange and impact-ionization processes which occur between plasma particles and recycled neutral particles in the vicinity of the divertor plate. (The neutral particle density profile is specified by the user, hence the neutral particles are not handled in a self-consistent manner). These atomic physics models may also be used as a source of sputtered impurity particles, which can then be followed by the code as a second ionic species. The dependence of the presheath and collector sheath potential drops, plasma temperature, flow velocity and parallel heat flux on the ratio of the charge exchange/ionization rate to the Coulomb collision frequency is being studied.

Implicit Simulations of Bounded Systems with the "Logical Sheath" Boundary Condition

The direct implicit method[2,3] has relaxed the $\omega_p \Delta t$ stability constraint associated with explicit particle simulation techniques, but the method is not accurate at large $\omega_{pe}\Delta t$ for bounded systems in which one wants to retain the dynamics of the sheath region. We have developed an alternative scheme (with S. E. Parker of the University of California at Berkeley) which does not resolve the sheath region, and yet provides an accurate description of the sheath potential drop and particle dynamics near the plate.[4] This is accomplished by implementing what we call the "logical sheath" steady-state boundary condition. The scheme maintains zero net current at the plate at each time step by absorbing all of the incident ions and an equal number of incident electrons. Excess electrons are specularly reflected from the plate boundary. The collector sheath drop is retained through the cut-off velocity of the electrons. Hence, small space and time scale resolution of the sheath region is not necessary.

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[2]Friedman, A., A. B. Langdon and B. I. Cohen, *Comm. on Plasma Phys. and Controlled Fusion*, **6** 225 (1981).

[3]Langdon, A. B., B. I. Cohen and A. Friedman, *J. Comput. Phys.*, **51**, 107, (1983).

[4]Parker, S. E., R. J. Procassini and C. K. Birdsall, "Particle Simulation of Bounded Plasmas with the Logical Sheath Boundary Condition," submitted for publication in *J. Comput. Phys.*, October 1989.

Comparison of PIC and FP Models of Mirror Plasmas

The transport and confinement of charged particles in an auxiliary-heated mirror plasma is modeled via a bounce-averaged Fokker-Planck (FP) code and a direct-implicit particle-in-cell (PIC) code. The test case studied is that of a tandem mirror end plug plasma which is heated by the injection of fundamental and second harmonic ECRH wave energy. This test case determines the confinement and transport of electrons only, with the ions modeled as scattering sites. Both electron-electron and electron-ion collisions are included. The magnetic and electrostatic fields are prescribed quantities. Each code employs a relativistic description of the electron dynamics in one spatial dimension. The modeling comparison is being divided into three sections: i) Benchmarking the physics results from the PIC code against those from the FP code; ii) A computational cost analysis of each code; iii) A discussion of the advantages and disadvantages of each code, including a comparison of the effort involved in setting up the simulations (both domain and input deck), and an assessment of the importance of self-consistency.

ASTROPHYSICAL PLASMAS

Principal Investigator: Jonathon Arons
University of California, Berkeley
Co-Investigators: A.B. Langdon, R. Klein, C.E. Max, H. Hoshino
Lawrence Livermore National Laboratory
Y. Gallant, D. Burnard
University of California, Berkeley

Abstract
The Institute was a joint sponsor of Professor J. Arons of UC Berkeley from July 1, 1988 to June 30, 1989, who did research on plasma astrophysics. Collaborative research was undertaken in three areas. First, one-dimensional simulations of relativistic plasma shocks were performed and there were supporting analytical calculations. Second, a cosmic-ray acceleration mechanism involving Alfvén waves upstream of strong shocks driven by supernovae was also studied. Third, time-dependent gas flows onto the polar cap of a neutron star were calculated.

Summary Report
The following provides a brief summary of this research. More detail is available in the final report for University of California PO No. B048706.

Transverse Relativistic Shocks

Much of Arons' effort has gone into the simulation and theory of relativistic shock waves in electron-positron and electron-positron-proton plasmas. These are thought to be associated with the acceleration of relativistic particles in astrophysical sources of synchrotron radiation, ranging from the Crab Nebula to active galactic nuclei and quasars. Arons, Berkeley graduate student Y. Gallant and A. B. Langdon worked on 1D PIC simulations of relativistic shock structure in pure e± plasmas using the code ZOHAR. Substantial effort has also gone into theoretical aspects of the shock structures, in a collaboration of Post-doc M. Hoshino and Arons. Arons and Hoshino further explored synchrotron masers as the physical process giving rise to the dissipation observed in the 1D shock simulations and carried out 1D simulations of transverse shocks in which the plasma is composed of electrons, positrons and protons, with the upstream flow being charge neutral with all species flowing at the same velocity. A new, and very interesting effect was discovered. Once the protons became unstable, the positrons showed further heating, in some cases forming a high temperature component with $T^{(+)}_{\mathrm{ho}} \sim T_{\mathrm{p}}$, while the electrons showed no further heating at all.

Several aspects of these results are in the process of being written up for publication. The new work on solitary waves and on the uniform medium simulations and theory of synchrotron masers should be submitted for publication by the end of the summer or by early fall. The theory of the Weibel instability in a relativistic plasma should be submitted not long after that. Further work on the 1D shock simulations is needed, in order to better understand the scaling of positron heating with the positron to proton density ratio, and to understand the effect of the downstream boundary conditions on the simulations. The theory of the fate of the downstream waves is in progress, using a quasi-linear model of the response of the particles to the waves generated at the shock. We are particularly interested in the fraction of the wave energy which might escape from shock, since this would be a directly observable signature of these shocks being present in synchrotron sources.

Cosmic Rays

Arons and C. Max completed a study of the interaction of streaming cosmic rays with Alfven waves upstream of the strong shocks driven by supernovae in the interstellar medium. This interaction is the basis of the most promising model for the acceleration of cosmic rays, in which pitch angle scattering of the high energy particles by the Alfven waves causes them to recross the shock many times, gaining energy by the Fermi process. In collaboration with a former student, Andrew Zachary, they used a new hybrid simulation code to study the development of the Alfven waves radiated by the drifting cosmic rays themselves. They applied their results to calculate the maximum energy of cosmic rays that can be produced by a single supernova remnant shock. They found that energy to be ~ 1000 GeV, about three orders of magnitude lower than is observed in the cosmic ray particles reaching the solar system. They reason for this is both the factor of > 30 increase in the particle scattering time in fields of a given amplitude obtained from the simulations, as compared to what one obtains from naive estimates, and also because as the supernova remnant simply doesn't live long enough to accelerate the whole spectrum. They discussed several changes in the astrophysical model, such as acceleration by the termination shock of a galactic wind, which might lead to improvements in the correspondence of the ever popular shock acceleration theory with observational reality. A paper describing these results is almost complete.

Polar Cap Accretion Onto Neutron Stars

Arons and R. I. Klein continued their study of time dependent gas flow onto the polar caps of magnetized neutron stars. The system under study is the flow of fully ionized plasma, falling under the force of gravity along the polar magnetic field of a strongly magnetized neutron star. The plasma is thermalized by a radiation dominated shock just above the stellar surface, where it forms a subsonically settling mound. This is a fundamentally multi-dimensional flow, since the radiation, whose pressure supports the mound against gravity, escapes by diffusing across the magnetic field even though the field confines the plasma. They have constructed a two-dimensional, time-dependent radiation gas dynamics codes which follows the flow of gas admitted with a specified pattern of mass flux as a function of magnetic flux at an upper boundary (usually taken to be 3 or 4 stellar radii). After a short initial adjustment period, the subsonic mound begins to boil, forming large scale radiation bubbles within the plasma. These bubbles are optically thin regions of positive buoyancy, with density in a bubble 3 or 4 orders of magnitude smaller than in the surrounding optically thick gas. The fluctuations in the flow introduced by the rise and bursting of thee bubbles may turn out to be the right interpretation of the luminosity fluctuations observed in the x-ray emission of the accretion powered pulsars and in some other classes of accreting neutron stars. A new method of flux limitation was derived which takes proper account of the flow of radiation through a closed hole in the plasma whose walls have variable radiative emissivity. This method was incorporated into an efficient numerical scheme for finding optically thin holes within the surrounding optically thick medium.

Berkeley graduate student, D. Burnard, Arons and Klein completed their study of polarized radiation transfer of x-rays in the strongly magnetized plasmas encountered in the polar regions of accreting neutron stars. They found a new method of solving the transfer equations including Comptonization which is $\sim 10^5$ times faster than those previously reported in the literature, which allowed them to go on and study the emission from atmospheres which have no special symmetry properties in the orientation of the magnetic field to the stratification directions in the atmosphere. A paper describing this technique is now in press in the Astrophysical Journal. They have constructed the first model of the emission, in which the density and temperature distributions in the mound come from a dynamical theory of accretion, rather than from ad hoc assumptions. They showed that variation of the source function with temperature at the layer where the thermalization optical depth in the atmosphere reaches unity is an interesting model for the high entropy photon spectra observed from these systems. A paper describing these results has been submitted to the Astrophysical Journal at the end of August.

Statistical Dynamics of Multi-Field Models for Plasma Turbulence

Principal Investigators: *J. A. Crotinger and A. E. Koniges*
Lawrence Livermore National Laboratory
P. A. Diamond
University of California, San Diego

Abstract

We are studying fundamental problems of turbulence in magnetized plasmas, concentrating on the statistical dynamics of multi-field models of drift wave turbulence.

Summary Report

Drift wave turbulence has emerged as a leading paradigm for low frequency turbulence and turbulent transport in a strongly magnetized plasma. The goal of our research is to understand the behavior of multiple field models of plasma turbulence with emphasis on the statistical interactions of the different fields. We are concentrating on a model of *collisional drift wave turbulence with coupled evolution equations for the* potential and density functions. The research involves study of the equilibrium statistical mechanics, development and validation of closure theories, and the statistical characterization of coherent structures.[5] This work has been supported by the PPRI since April, 1989.

We have begun development of a computer code to perform direct numerical simulations of the primitive model equations. This code employs a Fourier-spectral method and is designed for speed and efficiency on the CRAY-2 computer. The code will be sufficiently fast that, on the CRAY-2, we will be able to do a great many simulations at moderately high resolutions (80 x 80 and 128 x 128). We also hope to do a few very high resolution simulations (256 x 256 - 1024 x 1024). The code will run under the Livermore Basis system, making the development easier and giving the code a "user-friendly" interface. This code will be used to study the dynamics of the turbulent system including such important aspects as the direction of energy cascade, the assessment of turbulent steady states, and the characterizations/existence of coherent structures.

Our plans for the future include the development of a closure code which can be run alongside the direct numerical simulation. The closure code and related analytic closure study will allow us to make transport estimates and study issues such as the role of spectral anisotropy on relaxation and to explore the spectral dynamics of turbulent systems with sources and sinks.

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[5]Crotinger, J. A., Dannevik, W. P, Diamond, P. A., and Koniges, A. E., *Drift Wave Turbulence: Direct Simulation and Two-Point Closure Models*, Bull. Am. Phys. Soc. 34, in press (1989).

Large Scale Density Modifications Induced in the Ionosphere

Principal Investigator: *G. J. Morales*
University of California, Los Angeles
Co-Investigators: *J. D. Hansen, and J. E. Maggs*
University of California, Los Angeles
L. M. Duncan
Clemson University
Guy Dimonte
Lawrence Livermore National Laboratory

Abstract

An experiment was conducted at Arecibo in May, 1988 to heat and modify the nighttime ionosphere with intense high frequency (HF) radio waves. Simulation calculations with a 2-dimensional transport code reproduce the observations and indicate that large scale density depletions are generated which significantly refract the incoming rays.

Summary Report

Large scale density modifications can be produced in the ionosphere by localized temperature perturbations generated by an HF (3-10 MHz) wave near its reflection layer ($\omega \sim \omega_{pe}$). Since the particle and heat transport is predominantly along the geomagnetic field B, the process can be described by 1-dimensional energy and continuity equations[6]. Two dimensional effects are then taken into account by solving the equations on many adjacent field lines.

Experimental results from the heating campaign of May 3-6, 1988 at the Arecibo Observatory in Puerto Rico show that large modifications in the temperature $\delta T/T \sim 200\%$ and density $\delta n/n \sim 30\%$ occur at night because the energy density of the ionosphere is low compared to that of the HF waves. The modifications proceed from broad symmetric heating patterns to narrow tubes shifted northward, and the process has a highly reproducible universal state. The principal diagnostic is the received backscattered power of the 430 MHz radar at Arecibo as a function of altitude. Since the received signal is proportional[7] to $n/(1+T_eT_i)$ both density depletions and temperature increases simultaneously cause a decrease in the signal.

Interpretation of the results requires an understanding of the role of the tilted magnetic field lines. Since the transport is predominantly field-aligned, vertical positions along the diagnostic radar sample heating effects in different flux tubes. We find that the reflection surface aligns with the magnetic fields. Since most of the energy is absorbed near the O-mode

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[6] M. M. Shoucri, G. J. Morales, J. E. Maggs, *JGR* 89, 2907 (1984).

[7] J. V. Evans, Proc. of IEEE 57, 496 (1969).

reflection layer, this causes intense localized heating in a narrow ~ 10 km set of flux tubes.

To model the nonlinear refraction effects, the absorption term in the transport code is modified. Density and temperature perturbations due to the HF source are solved on 51 adjacent field lines spaced in the median plane by 2 km. The effect of the density changes on the distribution of the absorption is computed as follows. Initially, a horizontal gaussian absorption profile is assumed peaked at the unperturbed reflection layer. As the density evolves, the reflection surface is modified. Since O-mode rays near reflection have group velocities nearly perpendicular to B, the unperturbed HF rays are projected in this direction until the intercept the modified reflection surface between two field lines. The HF power contained in this ray is then assumed to be absorbed proportionately on these two field lines, and the calculation proceeds with the modified absorption profile. the density and temperature along the vertical line cutting across the computed field lines is used to model the diagnostic line of sight. Despite the simplicity of the "ray tracing" algorithm used, the agreement between the model and the experimental results is excellent.

Investigation of the Acoustic Decay Instability in Laser Plasma Interaction

Principal Investigators: *J. S. De Groot and Katsu Mizuno*
University of California, Davis
Co-Investigators: *Peter Young, Paul Drake and Kent Estabrook,*
Lawrence Livermore National Laboratory

Abstract

We have made extensive studies of the Ion Acoustic Decay Instability (IADI) in laser-produced plasmas using the Janus (Phoenix) laser at LLNL. We found that the threshold is quite low and that, in planar plasmas, it can be reduced to homogeneous-plasma, collisional values. These observations are consistent with the plasma-density profiles calculated by hydrodynamic simulations using the LASNEX computer code run with a flux limiter of $f = 0.1$. We have designed experiments to study the IADI in larger plasmas using the Nova laser.

Summary Report

The Ion Acoustic Decay Instability (IADI) occurs when a laser-light wave decays, within a plasma, into an electron-plasma wave and an ion-acoustic wave. The IADI generally occurs near the critical density of the laser-light wave, so that the Landau damping of the electron-plasma wave is not too large. The IADI is not only of fundamental interest to plasma physics, it is also potentially important for laser fusion because the electron-plasma waves produced by the IADI generate hot electrons that can preheat the fusion fuel and degrade compression. In the Janus experiments we used long laser pulses ($t_L \sim 1$ nsec) to irradiate large (up to 900 mm) spots at low laser intensities ($I_L = 3 \times 10^{12} \sim 10^{14}$ W/cm^2) with 1.06 μm laser light.

We found the IADI threshold to be quite sensitive to the laser spot size. As we increase the spot size, the geometry of the plasma expansion becomes more planar and less spherical and the gradient scale length of the plasma density increases. The observed threshold increased as the spot size decreased, being 5×10^{12}, 2×10^{13}, and 6×10^{13} W/cm^2 for spot sizes of 600, 350, and 100 mm diameter, respectively. This threshold is quite low and reaches the collisional value expected in a homogeneous plasma for the experiments having the largest spot size. The experimental results are compared with theory in Fig. 1, in which λ_{De} is the electron Debye length and k is the wavenumber of the electron-plasma wave. Larger values of $k\lambda_{De}$ correspond to lower plasma densities. Both the threshold value and the instability peak value of kl_{De} agree well with the theory. The experimental results are also consistent with the plasma density profile calculated by a hydrodynamic simulation using a flux limiter of $f = 0.1$ in the LASNEX computer code (the inset of Fig. 1). The results of our experiments are presented in a publication.[8]

The observed low threshold values indicate that the IADI is potentially important in large-scale-length plasmas, and should be evaluated for the conditions that apply to laser-fusion experiments. To this end, we have designed instrumentation to study the IADI in the hot, large-scale-length plasmas produced by the short-wavelength Nova laser.

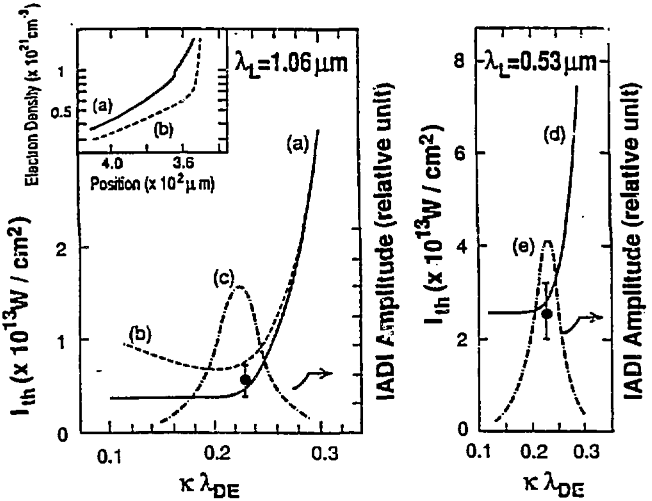

FIG. 1 The IADI threshold is shown as a function of $k\lambda_{De}$, with the solid circle showing the result from an experiment producing a relatively planar plasma. The curves show (a) the threshold values including collisional and Landau damping, (b) threshold values including convective losses as well, and (c) the calculated Stokes amplitude (see ref. 2) versus $k\lambda_{De}$. The inset shows plasma density profiles for $I_L = 5 \times 10^{12}$ W/cm^2, calculated using (a) flux limit f = 0.1, and (b) f = 0.3.

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[8]K. Mizuno, P. E. Young, W. Seka, R. Bahr, J. S. De Groot, R. P. Drake, and K. G. Estabrook "Investigation of the Ion Acoustic Decay Thresholds in Laser-Plasma Interaction," *Phys. Rev. Lett.* 65, 428 (1990).

Computer Simulation of Ionospheric Radio Frequency Heating

Principal Investigator: A. Y. Wong
Department of Physics, University of California, Los Angeles
Co-Investigators: R. A. Close, B. S. Bauer
Department of Physics, University of California, Los Angeles
A. B. Langdon, W. L. Kruer
Lawrence Livermore National Laboratory
E. Mjolhus
University of Tromso, Norway

Abstract

Two-dimensional electromagnetic particle simulations of ionospheric modification experiments at the HIPAS Observatory in Alaska were performed. The simulations were used to study the decay of the radio waves into electrostatic waves and the subsequent generation of cavitons wherein the electrostatic waves are strongly localized.

Summary Report

Linear and nonlinear absorption of electromagnetic waves in a warm, magnetized, nonuniform plasma were studied using an electromagnetic particle simulation code (ZOHAR) with either 1 or 2 spatial and 3 velocity dimensions. With fixed ions, finite temperature, and finite wave amplitude, transmission of the ordinary mode to the slow extraordinary wave (Z mode) was found to agree with cold plasma theory for linear conversion, and interference of mode converted waves is observed. With mobile ions and a parabolic density profile which peaks at the critical layer ($\omega_p = \omega$), the wave electric field was enhanced (factor of ten or more) near the critical layer where the wave becomes electrostatic, and small-scale density fluctuations (cavitons) were observed ($\delta l \sim 10\lambda_D$; $\delta n/n \sim 0.1$), typical of strong Langmuir turbulence. Wave damping and particle acceleration were also observed. The results were applied to ionospheric heating.